

R. D. Mac Nish 1, C. J. Peters 1, M. A. Schulte 1, D. C. Goodrich 2, D. R. Pool 3, T. Maddock III 1,
C. L. Unkrich 2, M. P. L. Whitaker 1, B. A. Goff 2

1 University of Arizona, Department of Hydrology and Water Resources, Tucson, Arizona, USA

2 USDA-ARS, Southwest Watershed Research Center, Tucson, Arizona, USA

3 U. S. Geological Survey, Water Resources Division, Tucson, Arizona, USA

1. INTRODUCTION

This paper presents preliminary findings on stream-aquifer interaction on a 425 meter long reach of the San Pedro River in Cochise County, Arizona. We present stream aquifer flux estimates made from streamflow measurements, and ground water head distributions acquired over 48 hour periods of intensive data collection (synoptic studies) in April and June of 1997. These two synoptic studies represent different degrees of stress created by the transpiration of riparian vegetation. This work is an important step towards attaining our ultimate goal of developing a better understanding of the interaction between streams and aquifers and improving our capability to simulate stream-aquifer systems.

The study reach at Lewis Springs (about 13 km east of Sierra Vista, AZ) is underlain by a floodplain aquifer deposited by the San Pedro river in a valley carved in a regional aquifer. The regional aquifer is comprised of alluvial materials deposited by streams exiting the bordering ranges prior to late Pliocene to middle Pleistocene time (Huckleberry, 1996), when the San Pedro River became established as a through-flowing drainage. Similar closed basins in this area often have lacustrine silts and clays near the basin center, and preliminary geophysical exploration has indicated a body of fine-grained materials to the west of the Lewis Springs site (Pool, 1997). The floodplain aquifer in the study reach ranges from 0 to about ten meters in thickness, feathering out against the underlying regional aquifer at its margins. In the regional flow system, water moves toward the stream from the bordering mountains in the regional aquifer, discharges to the floodplain aquifer, and then moves down valley and toward the stream, resulting in water discharging to the stream.

Corresponding author address: Robert D. Mac Nish, Dept. Of Hydrology & Water Resources, University of Arizona, Tucson, AZ 85721; e-mail address macnish@hwr.arizona.edu

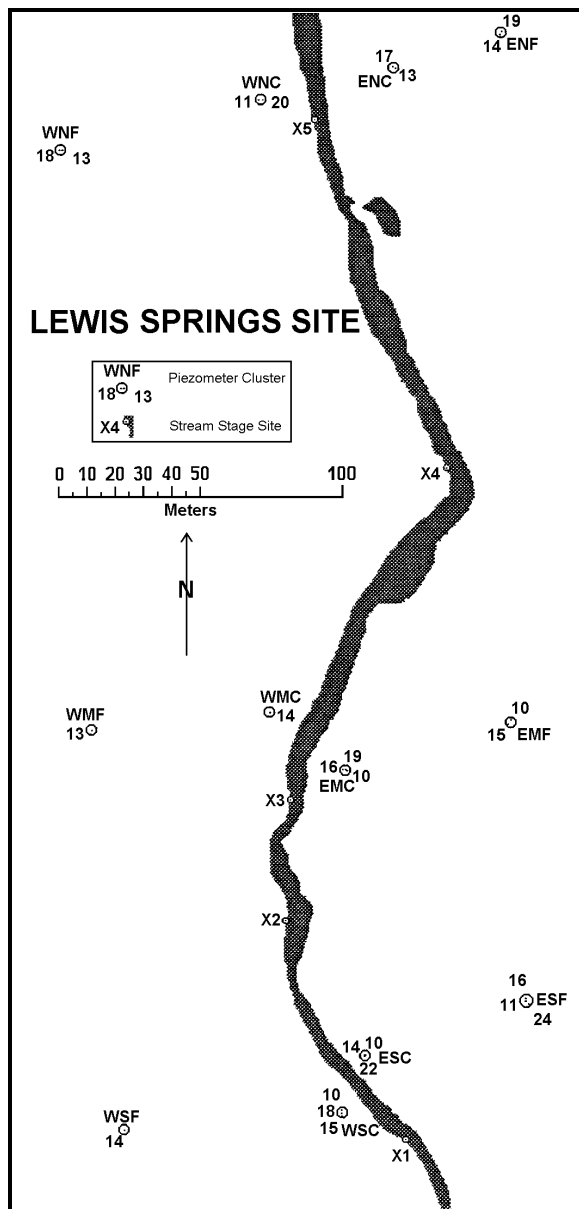


Figure 1. Site Map of the Lewis Springs Study Site showing piezometer and stream data collection sites in relation to the San Pedro River.

2. DATA ACQUISITION

Ground water data were collected on an hourly basis at 25 piezometers, and continuously recorded at 6 wells and one piezometer. The 25 piezometers measured on an hourly basis were constructed by drilling a 50 mm diameter hole with a truck-mounted auger, inserting a 38 mm diameter galvanized steel pipe with a plastic cap over the base to the target depth of the piezometer. Then a 12.7 mm steel conduit tube with the lower 25 cm slotted with a hacksaw and capped with a plastic cap was inserted in the 38 mm pipe and the annulus filled to a depth of 30 cm with sand, followed by another 30 to 50 cm of clay pellets and the remainder with materials drawn from the hole when it was drilled. The 12.7 mm tube was then tapped to dislodge the plastic cap from the bottom of the 38 mm pipe, and the 38 mm pipe was withdrawn from the hole. A 1.5 meter length of the 38 mm pipe with a steel cap was left in the hole with 40 cm standing above the land surface to protect the thin-walled conduit piezometer. The 6 wells were constructed with 10 cm diameter PVC pipe, slotted in the lowest 1.5 meters. The wells were emplaced in 15 cm diameter holes drilled with an auger rig, and the tops of the PVC wells were protected by the installation of 15 cm diameter steel casing set in concrete. The annuluses between the PVC and the auger hole were backfilled with the materials brought to the surface by the auger during drilling.

The network design resulted in three transects roughly perpendicular to the stream in the study reach, with each transect comprised of four clusters of wells and/or piezometers with one piezometer finished just below the water table, and one or two additional wells or piezometers finished 1.5 meters or more below the shallowest piezometer. The clusters in each transect included one on each side of, and close to, the stream channel, and another cluster on each side of the stream about 50 meters further from the stream channel than the stream-side clusters. The clusters are identified by which side of the stream they are on (**West** or **East**), their location along the reach (**North**, **Middle**, or **South**), and their proximity to the stream (**Close** or **Far**). Within each cluster each piezometer is assigned a number which is the piezometers approximate depth in feet. Thus **ESC 10** is about 10' deep, and in the cluster on the east side of the stream at the south end of the study reach close to the stream. Some data on water levels were also taken from twelve neutron probe access tubes located between the two upstream transects, and open to the aquifer just below the

water table (see Figure 2, Goodrich et. al., this issue, and Whitaker et. al., this issue) Water level measurements were made with an electronic sounder that could be read to 1 mm. Analysis of the data from the piezometers during and after emplacement indicate the **ENF** cluster wells are both completed in the regional aquifer, and could not be used in constructing water level contours in the floodplain aquifer. There is only a single piezometer at the **WSF** cluster because the regional aquifer was encountered at 4.5 meters. During both synoptic periods even the shallow piezometer at **WSF** appears to be slightly influenced by higher heads in the regional aquifer

Several methods were used to monitor streamflow in the San Pedro River during each synoptic period. Direct stage measurements, tracer dilution samples, and bubble-gauge readings of stage were taken at five cross sections along the study reach (Figure 1). Direct stage measurements were taken using a staff gage or by monitoring water levels in a stilling well. For the dilution gaging, rhodamine-WT dye was injected upstream of the first cross section. Bubble gage sensors were installed at most cross sections. Additionally, a flume was installed upstream of the first cross-section during the June synoptic period. Detailed discussion of these measurement techniques can be found in Rantz et al (1982).

Except at the **X3** site, direct stage readings are difficult to translate into absolute or relative discharge numbers for want of reliable stage-discharge rating curves for the study reach. Therefore, tracer dilution gaging data were used to determine preliminary results, though the dilution gaging was not without complications. Dilution gaging assumes that the dye is well-mixed in the stream. To ensure such a well-mixed system, dye was injected into the stream at a point approximately 200 meters upstream of the first cross section so that mixing in the pools and riffles above the study reach would create an even distribution of dye concentration. Comparing samples from several points across each downstream cross-section demonstrated that the dye/streamflow mixture was indeed well-mixed. Traditional continuous-injection dilution gaging also assumes that the dye injection rate is constant and that the stream discharge does not change significantly. Discerning groundwater baseflow into the stream over a period of several days precludes the latter assumption, though the rate of change in stream flow was slow in comparison to the travel time through the study reach. In addition, field

conditions and the simplicity of our injection apparatus resulted in a dye injection rate that had a diurnal variation of 50%. The injection apparatus consisted of a 2-gallon plastic gasoline can fitted with a valved tube leading to a regulator valve normally used to administer intravenous fluids. This apparatus was unable to maintain a constant dye injection rate as the viscosity of the dye solution varied with ambient air temperature.

3. RESULTS

Groundwater elevation maps constructed for 0600 on April 20, 1997 and 0700 on June 8, 1997 with data from the shallowest piezometers in the floodplain aquifer are shown on Figure 2. Inspection of the figure shows that while the pattern of flow was similar during both synoptic periods, with strongly converging flow toward the stream at the upstream end and weakly converging flow downstream, the gradient was lower by about 15% in June. The downstream groundwater levels dropped approximately 7.5 centimeters, while at the upstream end, a drop of about 15 centimeters occurred. The stronger convergence of flow at the upstream end of the study reach is probably related to the gradient of the stream channel which is greater in the southern part of the study reach.

Piezometric surface maps constructed for the deeper piezometers in the floodplain aquifer are shown in Figure 3. The shapes of the contours are similar for the two periods of time, but have a significantly different character than the shallower piezometers in the southern part of the area. Gradients in the underlying regional aquifer have been shown to be to the west (Pool, 1997), and it is possible that the potentiometric surface in the lowest layers of the floodplain aquifer reflects that gradient. The heads in the lower part of the floodplain aquifer dropped from April to June, with the greatest change near the upstream end where heads dropped about 15 centimeters. Heads at the downstream end dropped about 5 centimeters. The vertical gradient in the floodplain aquifer is upward in most of the area, as can be seen in Figure 4, which show the differences between shallow and deep piezometers for the April and June synoptic periods at the **ESC** piezometer cluster. The upward gradient in June was significantly greater than in April, reflecting a greater drop in the shallow piezometer than in the deeper piezometer. The data is "noisy" as each point is derived from two measurements. The high and fluctuating section of the April trace coincides with a measurement shift, and may reflect on a less proficient observer rather than hydrologic reality.

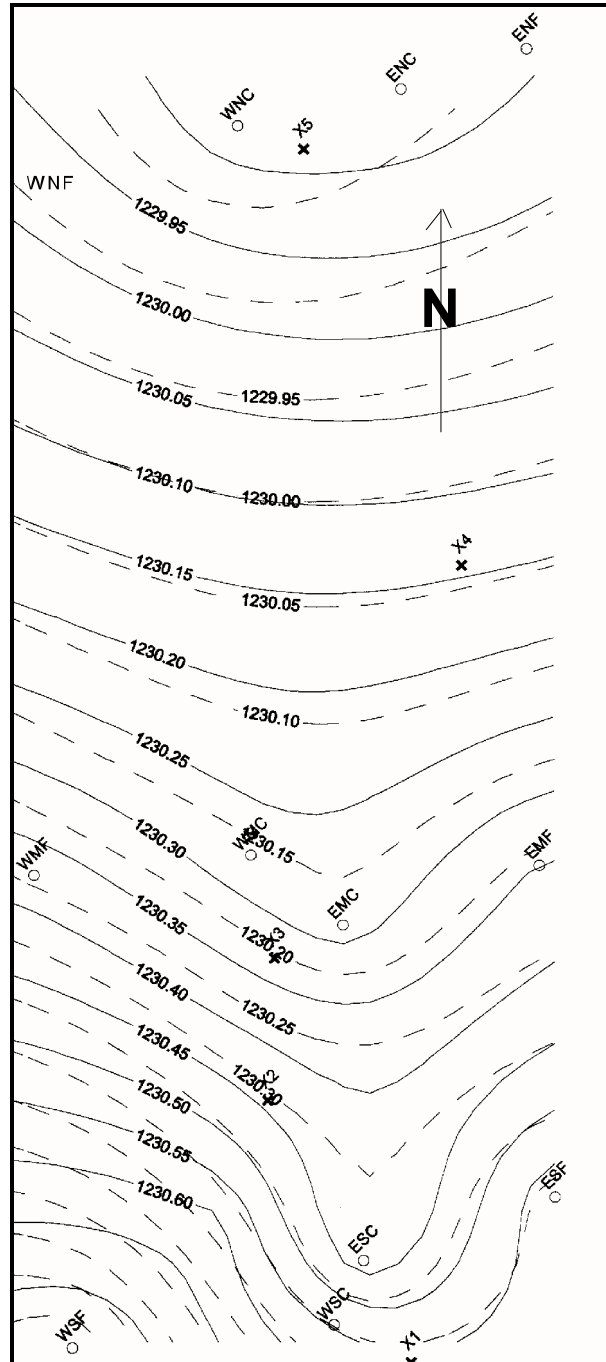


Figure 2. Elevation maps of the water table in the Floodplain Aquifer at 0600 04/20/97 (Solid), and 0700 06/08/97 (Dashed).

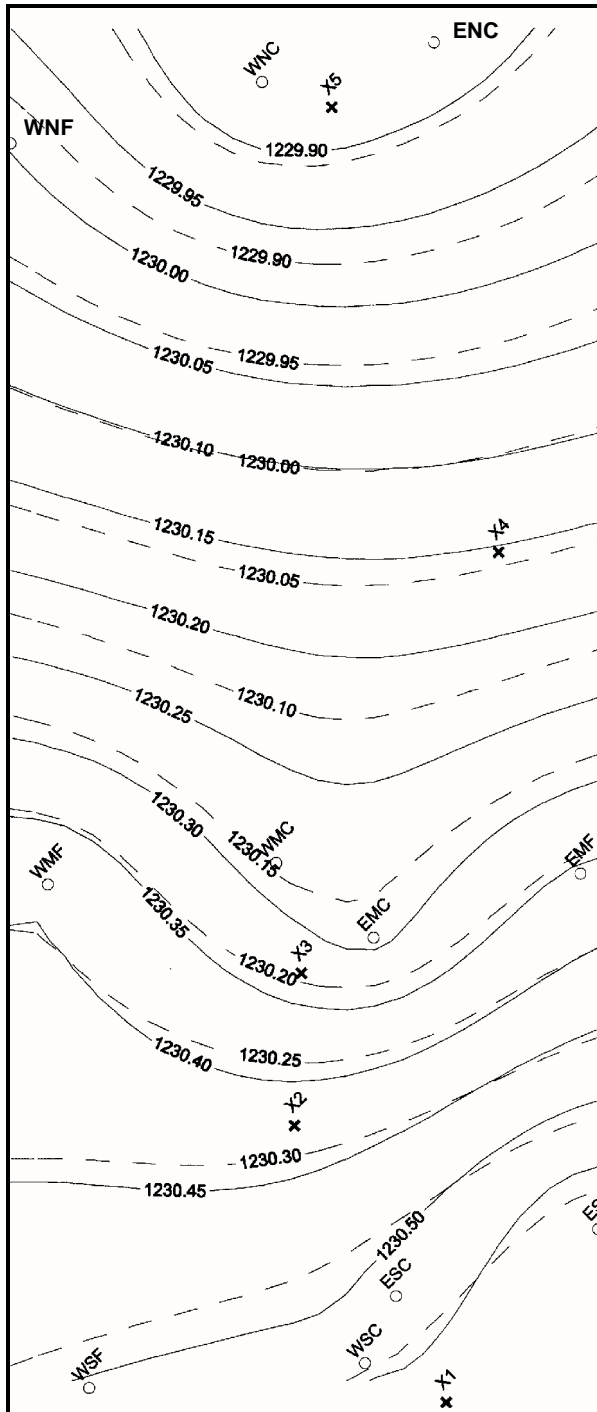


Figure 3. Piezometric surface maps of the lower part of the Floodplain Aquifer at 0600 04/20/97 (Solid), and 0700 06/08/97 (Dashed).

Over the course of each of the 48-hour synoptics, there were fluctuations in the water table due to the effects of phreatophyte transpiration.

Figure 5 shows the contrast between the two synoptics at the ESC 10 piezometer. The diurnal fluctuation is more pronounced in the June synoptic when the riparian vegetation was transpiring at near maximum rates, while in April, the trees were just leafing out, and the rate of transpiration was significantly less.

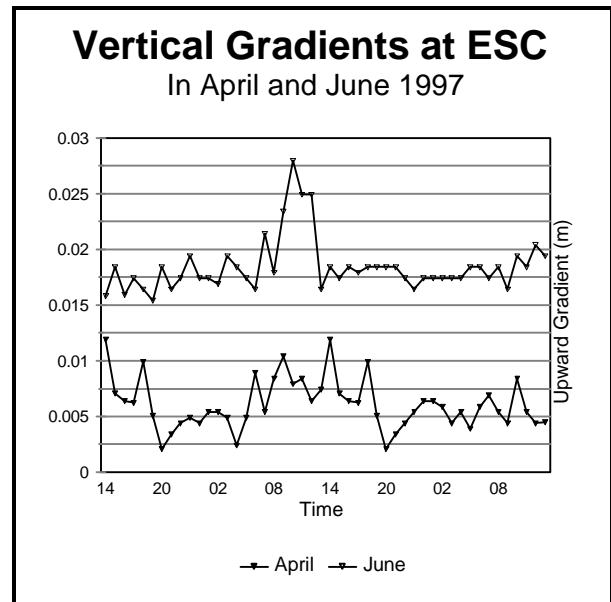


Figure 4. Comparison of vertical gradients during the April and June Synoptics at **ESC** cluster.

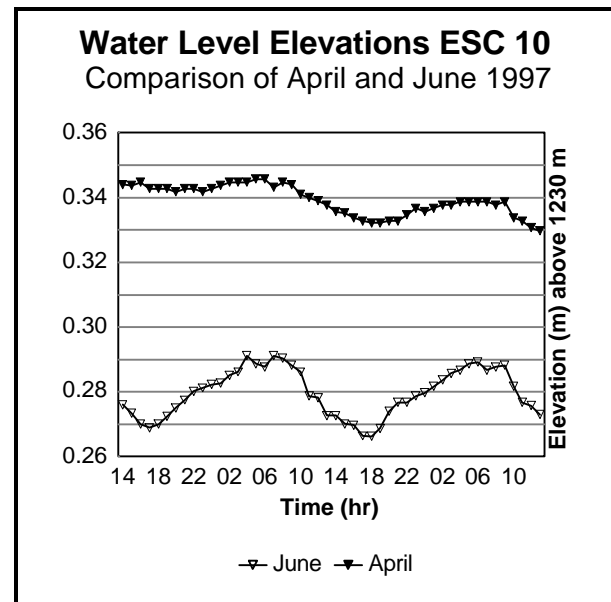


Figure 5. Comparison of water level elevations and fluctuations in the floodplain aquifer at **ESC-10**.

Until the problems in analyzing the varying dye injection rate can be resolved, it will not be possible to confidently develop an estimate of the streamflow itself. However, by analyzing the relative changes in dye concentration between sampling points and combining this information with streamflow measurements made during the synoptic periods by other means, it is possible to estimate the gains in streamflow between cross-sections using the data collected. First, a Fourier series model was used to fit curves to the dilution gaging data at each cross section. The time of travel between sections was estimated by comparing similar points on each curve. A mean stream velocity, assumed constant through the study reach, was determined by minimizing the difference between the estimated gain in discharge between the first and last cross-sections and the cumulative gain between consecutive cross-sections. The relative gain in discharge (Q) between two cross-sections was found by comparing the dye concentrations at those cross-sections using a simple mass-balance formula:

$$\frac{Q_i + \Delta Q_{i-j}}{Q_i} = \frac{S_i}{S_j} \quad (1)$$

Table 1 summarizes results of this analysis for the two times under consideration.

TABLE 1

Section	April	June
X1	135 l/s *	23.2 l/s **
% Gain	0.88 %	1.05%
X2	136 l/s	23.5 l/s
% Gain	0.49 %	1.05 %
X3	137 l/s	23.8 l/s
% Gain	1.60 %	1.31 %
X4	139 l/s	25.5 l/s
% Gain	1.67 %	— ***
X5	141 l/s	--

* flow estimated from pygmy meter measurements

** flow measured by Parshall flume

*** dye concentration plateau not reached in June at the time of sampling.

Estimated baseflow to the stream in June is about one-third of the contribution in April, though the June contributions account for a larger percentage of stream discharge. Possible confounding factors not included in this preliminary analysis include dye losses due to photodegradation and sorption onto clay particles. Dye losses would result in the over-estimation of groundwater baseflow to the stream. Over these short periods of time it is likely that such losses will prove insignificant.

4. CONCLUSIONS

The sharply converging flow paths in the floodplain aquifer at the water table in the upstream end of the study reach may result from lower hydraulic conductivities in this part of the aquifer as compared to the northern part of the study area. This is supported by the differences in the baseflow changes in the two areas, though one has to consider the lengths of the two southern segments are considerably shorter than the two northern segments.

A reduction of 15% in the downstream gradient in the ground water system between April and June may compare well with a 33% reduction in baseflow contribution to streamflow after data on changes in stream-bottom area are incorporated into the analysis.

The greater declines in water levels in the floodplain aquifer near the upstream end of the reach may be related to more phreatophyte activity in that area. When data collected in other experiments on sap flow and moisture fluxes in and above the riparian canopy has been analyzed, those results may explain some of the variations seen in the water level data (Williams et. al., this issue).

The seasonal variation in vertical gradients, particularly in the southern part of the study area, are driven by the phenomenon described in the paragraph above. The fact that water pressure in the deeper parts of the floodplain aquifer declines less than the water table results in the increase in upward gradient. Again, analysis of the ET stresses on the various parts of the study area may give us insight to the causative factors for the changes we have observed in water levels and gradients.

5. ACKNOWLEDGMENTS

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6. REFERENCES

- Goodrich, D. C., 1997, et. al., 1997, An Overview of the 1997 Activities of the Semi-Arid Land-Surface-Atmosphere (SALSA) Program. (1.1, this issue)
- Huckleberry, G., 1996, Historical Channel Changes on the San Pedro River, Southeastern Arizona, Arizona Geological Survey Open-File Report 96-15, 21p.
- Pool, D. R., and Coes, A. L., 1997, Hydrogeologic Investigations of the Sierra Vista Sub-basin of the Upper San Pedro River Basin, Southeast Arizona: U. S. G. S. Water Resources Investigation, Manuscript in review.
- Rantz, S. E. and others. 1982. Measurement and Computation of Streamflow - Volume 1. Measurement of stage and discharge: U. S. Geological Survey Water-Supply Paper 2175, 284p.
- 1982, Measurement and Computation of Streamflow - Volume 2, Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631p.
- Whitaker, M. P. L., et. al., 1997, Monitoring Bank Storage in the San Pedro Riparian National Conservation Area, Arizona. (P2.13, this issue)
- Williams, D. G., et. al., 1997, Biotic Control over the Functioning of Desert Riparian Ecosystems, (1.11, this issue)